Lattice-Automaton Modelling of Bioturbation and Benthic Activity

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LONG-TERM GOALS

My long term goal is a quantitative and mechanistic understanding of the relationship between infaunal ecology, their actions and their rates and the consequent modification of sediments, including the creation and destruction of heterogeneities and the modes and rates of sediment component mixing.

OBJECTIVES

The development of a model/computer code that embraces the discrete nature of sediments and organisms, rather than averaging it away, and that utilizes biologically relevant parameters, such as animal sizes, population density, feeding and locomotion rates, and probabilities for observed behaviour(s), to drive the model and produce predictions about sediment composition and fabric.

APPROACH

My approach is the direct modelling of organism-sediment interactions via a new type of model. Biologically active sediment is represented on a computer as a regular lattice of quasi-particles with individually assigned chemical, biological or physical properties. Model benthic organisms are introduced in the form of automatons, i.e. programmable entities, that are capable of moving through the particle lattice by displacing or ingesting-defecating particles. Each automaton obeys a set of rules, both deterministic and stochastic, designed to mimic real organism behavior, and different types of organisms have different sets of rules.

WORK COMPLETED

The computer code of this model for small deposit feeders, which caries the acronym LABS, is complete and extensive study of the effect of these organisms on tracer distributions has been completed and is now in press. (This constitutes the validation phase of the project.)

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14. ABSTRACT
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15. SUBJECT TERMS

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RESULTS

The results from the model are, so far, of two types: fabric representations and tracer distributions.

<u>Fabric</u>: 2D visualizations of state of a sediments particle distribution provide immediate appreciation of the consequences of animal actions on sediment fabric and composition, including the development of biologically-induced heterogeneities, which are observed in real sediments. Figure 1A illustrates an initial random fabric with four worms beginning to process the sediment; Fig. 1B shows the effects of burrowing and packaging after 100 days, i.e., the sediment fabric is now dominated by the biological features.

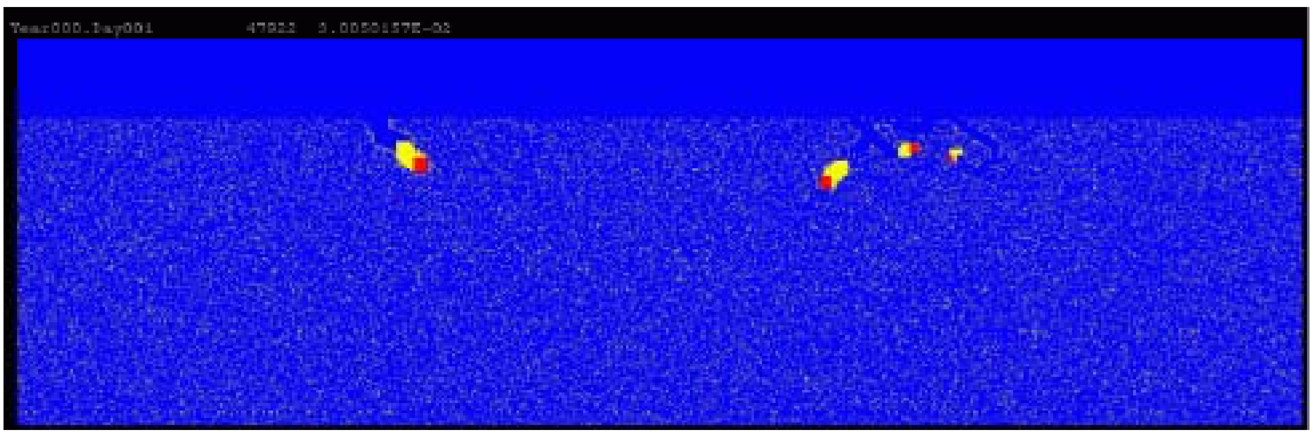

Figure 1A. Sediment with an initial random distribution of particles (white) and water (blue), with porosity of 0.8, and distinct sediment-water interface. Four small deposit-feeding worms (yellow with red heads) are beginning to rework the sediment. (Sediment is 50 cmX25 cm, worms are 1-4 cm in length.)

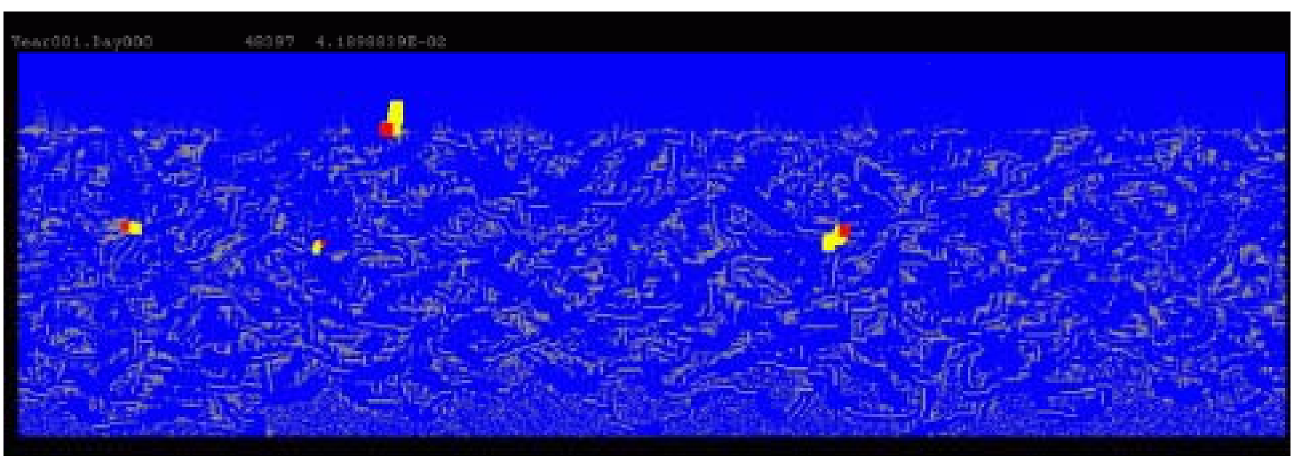

Figure 1B. Same sediment after 1 year of reworking. Note burrows and heterogeneities.

These results (Fig. 1) allow study of both the size and the rate of change of the heterogeneity with time and as a function of animal parameters, such as size and number.

Tracer Distributions: Each particle in the model can be tagged with a selected amount of tracer, and this can be modified with time. Thus, it is possible to simulate the arrival of particle specific tracers, like ^{210}Pb, that are used to estimate mixing rates in natural sediments. From the model 2D distribution of ^{210}Pb, it is then possible to create a synthetic 1D ^{210}Pb profile with depth (Figure 2), and from that profile calculate apparent mixing coefficient values, D_B, as is done for real sediments.

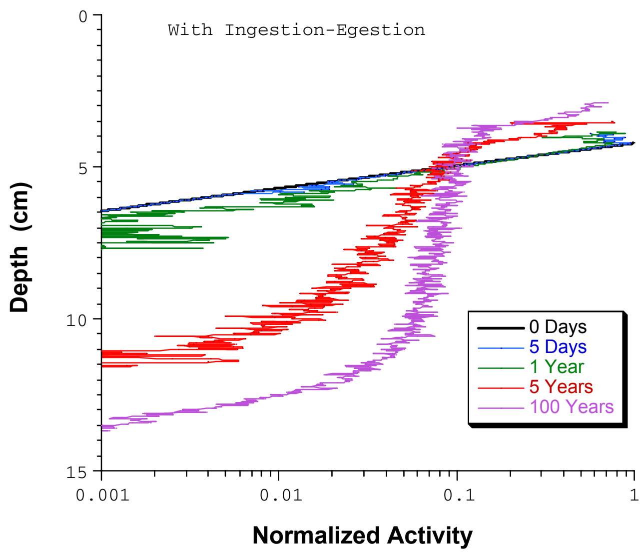

Figure 2. Synthetic ^{210}Pb profiles obtained by laterally averaging the ^{210}Pb concentrations in the 2D model (one organism, 0.0cm/yr sedimentation, 1-10 g/d feeding rate, 1-10 cm/d locomotion rate.) The steady state profile at 100 years (pink-violet) can the be modelled with a standard diffusion model to obtain D_B values.

All model runs of LABS are done with literature quoted biological parameter values, without any a priori adjustments. Typical values of D_B as a function of animal locomotion speed (with and without ingestion-egestion), animal numbers, mouth size, are shown in Figure 3 (see also Boudreau et al., in press, as listed below, for a more extensive discussion of these results). The range of D_B values is very much that seen in real sediments, which validates the model and illustrates for the first time the link between specific animal activities and D_B.

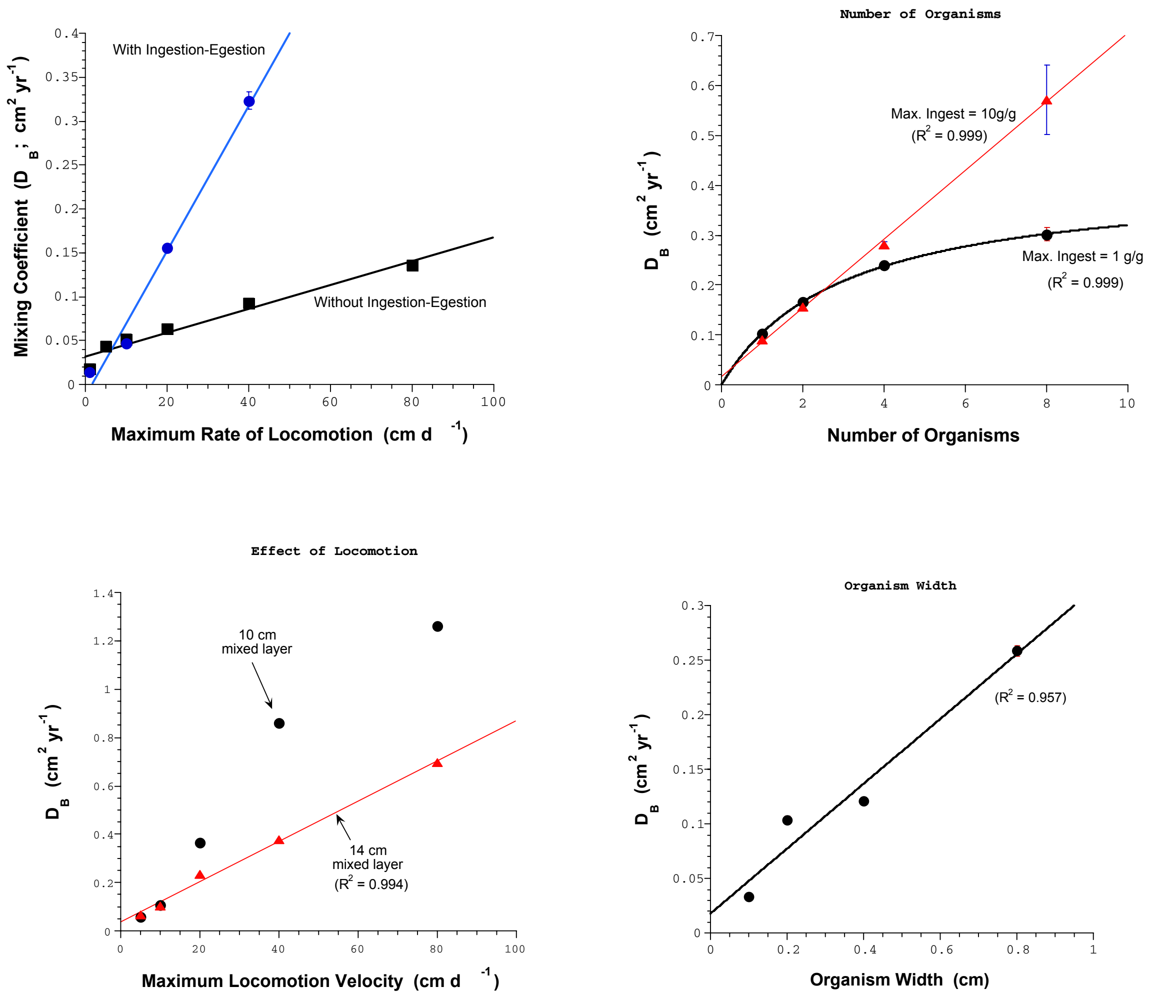

Figure 3. Plots showing the dependence of D_B on locomotion, number of organisms, mixing depth and organism width, as observed in the small deposit-feeder implementation of the LABS code.

Conversely to a specific steady state tracer, it is possible to label all particle with a number and simply calculate D_B from the time-dependent standard-deviation (displacements) of the entire population of particles, $\overline{\Delta^2}$,

$$\overline{\Delta^2} = 4\, D_B\, t$$

Such a function is plotted in Figures 4. The trend in the results is linear for times greater or equal to about 1 year. The calculated D_B values are in line with the ^{210}Pb results. At early times, however, the trend is strongly non-linear, indicating that D_B is then a function of time. This has important implications for some types of tracer studies where an experimenter salts the sediment-water interface with tagged particles. Such experiment must have a duration of at least 9-12 months if the true D_B value is to be obtained, and this has not always been the case.

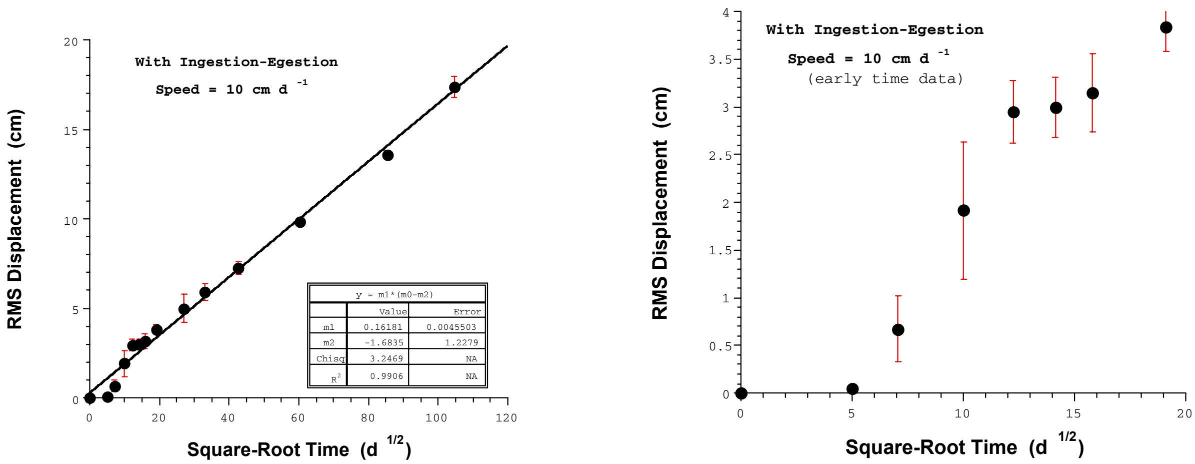

Figure 4. Plot of the root-mean-square displacement of all the particles in a 2D simulation as a function of time. Left-hand diagram is for the entire time ranged used, while the right-hand diagram is for early times.

Even at this early stage, the lattice-automaton model is providing significant insight into the working of bioturbation and our standard means of measuring and quantifying these effects.

IMPACT/APPLICATIONS

The model needs to be explanded to a broader ecology of infaunal functional types before it can be considered to be a realistic simulation of sediments. Nevertheless, the results so far are highly encouraging, and we may soon have a computer-based method of simulating relatively complete benthic ecologies and their effects.

TRANSITIONS

The LABS has been given to my NICOP partners and will soon be in the public domain via publications listed below.

RELATED PROJECTS

Larry Mayer and Peter Jumars at the Darling Center are collecting data we can use to extend the model, including transformation of sediments by passage through an animal's gut.

PUBLICATIONS

Choi, J., François-Carcaillet, F. and Boudreau, B.P. (in press) Lattice-automaton bioturbation simulator (LABS): Implementation for small deposit feeders. Computers and Geosciences, October issue.

Boudreau, B.P., Choi, J. and François-Carcaillet, F. (in press) Diffusion in a lattice-automaton model of bioturbation by small deposit feeders. Journal of Marine Research, september issue.